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**Inspection of Demonstrator  
Bonded Repairs on a  
QANTAS 747-300: September 1999**

Rowan C. Geddes

DSTO-TR-0900

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**Airframes and Engines Division**  
Aeronautical and Maritime Research Laboratory

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## ABSTRACT

A visit to the QANTAS Jetbase at Sydney Airport was undertaken to inspect the condition of nine demonstrator bonded repairs which were applied to a Boeing 747, registration VH-EBW in 1990. The repairs had seen in excess of 37,000 hours of service since they were applied to regions of the aircraft which are susceptible to foreign object damage. Most of the repairs exhibited a degree of erosion damage, yet had still maintained their original bond integrity.

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# Inspection of Demonstrator Bonded Repairs on a QANTAS 747-300: September 1999

## Executive Summary

Adhesively bonded composite repairs have been demonstrated to be a highly cost effective method for repairing and reinforcing defects in aircraft structure. Perhaps the most critical aspect of this technology is the durability of the adhesive bond between the repair and the structure. Effective, specialised surface treatment prior to bonding of the repair is required to ensure satisfactory bond durability. This quality-controlled process provides the primary level of confidence for the long-term effectiveness of the bonded repair.

In October 1990 a series of nine demonstrator bonded repairs were applied to a QANTAS aircraft as part of a program conducted by the Boeing Commercial Aircraft Company (Boeing) and the Aeronautical and Maritime Research Laboratories (AMRL) to assess the long term durability of bonded repairs to aircraft structure.

After nine years of service in a range of environments, AMRL personnel inspected the repairs to the QANTAS aircraft. It was found that after more than 37,000 airframe hours (afhrs) of service several of the more exposed repairs had suffered from erosion damage. Despite this damage, the repairs retained their bond integrity and the repairs had continued to function.

Additionally, there were no signs of cracking in the aluminium skin surrounding the repairs implying that their presence did not lead to other structural problems such as fatigue in the aluminium skins.

The results of this long-term service environmental program demonstrated that the durability of bonded repairs is high even when exposed to extreme climatic, erosion and aerodynamic conditions.

## Authors

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*Rowan Geddes joined AMRL as a Professional Officer in August 1998, and has completed both a degree in Aerospace Engineering (hons) and an Associate Diploma of Aerospace Systems Engineering at RMIT. He is an active committee member of the Melbourne Branch of the Royal Aeronautical Society. Rowan is currently working within the Composites Functional Area at AED, AMRL.*

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## 1. Introduction

In October of 1990 a series of demonstrator bonded repairs were applied to a QANTAS B747-300 aircraft as part of a program conducted by the Boeing Commercial Airplane Company, QANTAS Airways Limited (QANTAS) and the Aeronautical and Maritime Research Laboratory (AMRL) [1] to assess and demonstrate the durability of bonded repairs for civilian aircraft use.

As at Tuesday 8<sup>th</sup> August 1999, aircraft VH-EBW had 57,045 airframe hours (afhrs) and 10,905 landings during service. The repairs were fitted in October 1990, when the aircraft had 20,010 afhrs and 3885 landings. Therefore the repairs had seen in excess of 37,000 hours of service and 7020 landings in a nine-year period. During this period the aircraft's movements were typically international, with the main destinations being Rome, Denpasar, Christchurch and Los Angeles. This indicates that the aircraft was exposed to a variety of service environments while the demonstrator repairs were fitted.

The demonstrator repairs in the program were placed in areas of the QANTAS 747-300 aircraft that were known to be prone to corrosion damage, bird strikes, stone and Foreign Object (FO) strikes as well as areas prone to oil and grease. In all nine demonstrator repairs were applied to the aircraft as shown in Figure 1.

Since they were applied to the aircraft, QANTAS staff have carried out visual inspections of the repairs during 'C' and 'D' checks. More thorough tap test and acoustic inspections were carried out by QANTAS Non Destructive Evaluation (NDE) technicians in 1992 and again in 1998.

This report describes the inspection and evaluation of these demonstrator repairs by an AMRL Engineer (the author) in September of 1999. The author was accompanied during the inspection, by QANTAS engineering and maintenance staff.

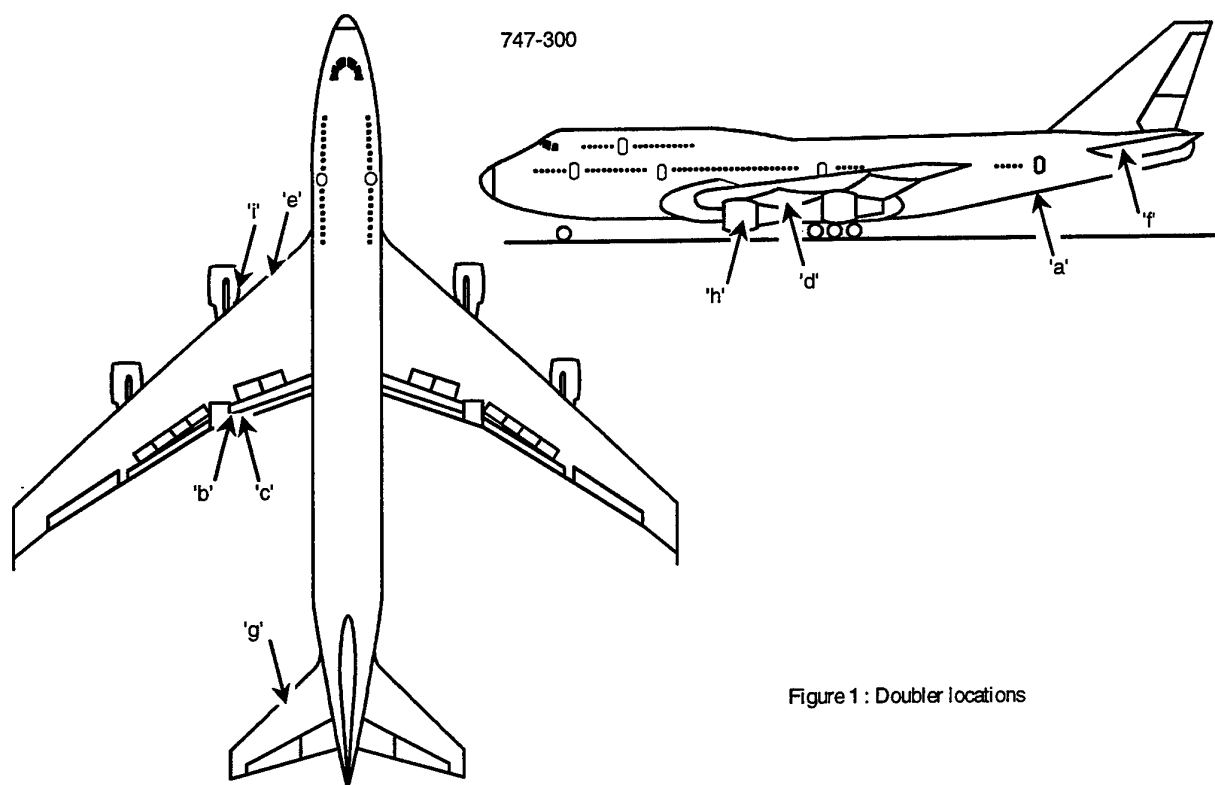


Figure 1: Doubler locations

Of the nine demonstrator repairs originally applied to the aircraft (registration number VH-EBW), seven were inspected. The other two were on the engine reverser cowls on engine no. 12758, which was moved from VH-EBW to aircraft VH-EBX.

## 2. Inspection Results

### 2.1 Inspection Technique

Initial inspection of the repairs and the surrounding aluminium structure was by a visual inspection. A tap test was then carried out over the repair. The edges of the repairs were inspected to assess the integrity of the adhesive. Inspection of the surrounding aluminium structure was carried out to look for signs of fatigue cracks due to the presence of the repair. Photographs were taken of any damage and the results documented.

### 2.2 Results

Referring to Figure 1 [1], the locations that were chosen in the initial program to place the repairs were:



- a. The external fuselage-skin longitudinal lap-joint located at BS 2050 at stringer 46L.
- b. Left hand side, inboard trailing-edge midflap. Located on the upper, aft midspar panel 300 mm from the outboard edge and 150 mm aft of the Teflon rubbing strip.
- c. Left hand side inboard trailing edge midflap. Located on the lower forward midspar-panel, 460 mm from the outboard edge and 150 mm aft of the forward edge.
- d. Number 2 engine-pylon aft fairing on the hydraulic bay access door 150mm forward of the aft edge.
- e. The left-hand side wing, fixed leading-edge nose, located at inboard leading edge station 395.
- f. The lower leading-edge skin panel of the left hand horizontal stabiliser, station 397, 300 mm forward of the front spar.
- g. The leading-edge nose skin panel of the left-hand horizontal stabiliser, station 390.
- h. The thrust reverser cowl, translating-sleeve number 2 engine, serial number 12758, located outboard at the 8 o'clock position (looking forward), on the external skin, at the aft edge of the sleeve.
- i. The thrust reverser cowl, translating-sleeve number 2 engine, serial number 12758, located inboard at the 4 o'clock position (looking forward) on the external skin at the aft edge of the sleeve.

Locations 'h' and 'i' were not inspected as engine 12758 had been moved to aircraft VH-EBX. However inspection of VH-EBX on Wednesday 8<sup>th</sup> September revealed that the thrust reverser-cowls had been replaced. The location of the cowls with the repairs was not known.

The following table [1] details the repair geometry and adhesive systems used for each repair. Each repair was square, with dimension 'A' indicating the side length.

Repair Location	Adhesive Type	Cure Time (hours)	Cure temperature (° C)	Size 'A' (mm)	Plies
'a'	FM73	8	80	200	12/4
'b'	FM73	8	80	100	4
'c'	V201	1	RT	150	4
'd'	V201	1	RT	150	4
'e'	FM73	1	120	200	4
'f'	V201	1	RT	146	4
'g'	FM73	1	120	100	4
'h'	FM73	1	120	110	3
'i'	V201	1	RT	110	3

RT= Room temperature; V201= Versilok 201

### 2.2.1 Location 'a' - Lap Joint

Inspection of this repair proved difficult, as there was a thick layer of paint over the repair. Tap test and visual inspection showed no signs of degradation of the repair. There was a small crack in the paint at the aft edge of the repair running in the longitudinal direction as shown in Figure 2.

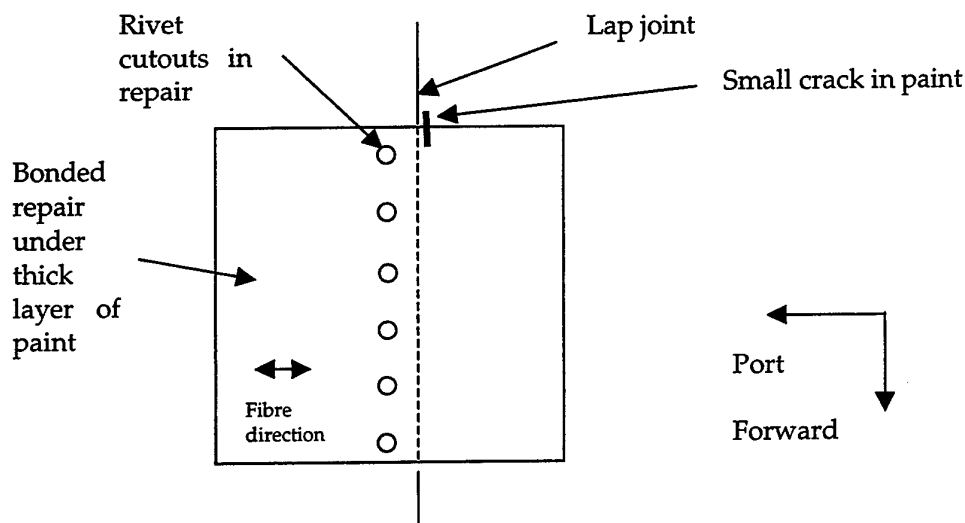


Figure 2. Orientation of repair at location 'a', showing crack in paint.

### 2.2.2 Location 'b' – Trailing Edge Mid-Flap Upper Surface

Visual inspection showed that the repair was in excellent condition, with a small crack in the covering-coat of paint along the width of the repair at the trailing edge. A tap test suggested that the repair had disbonded along this edge to a depth of approximately 20mm. There were no signs of erosion or impact damage. The aluminium skin in this region was rather flexible, with no support structure underneath. The map of the disbond indication is shown in figure 3. Photograph 1 shows the repair on the aircraft and the region in question.

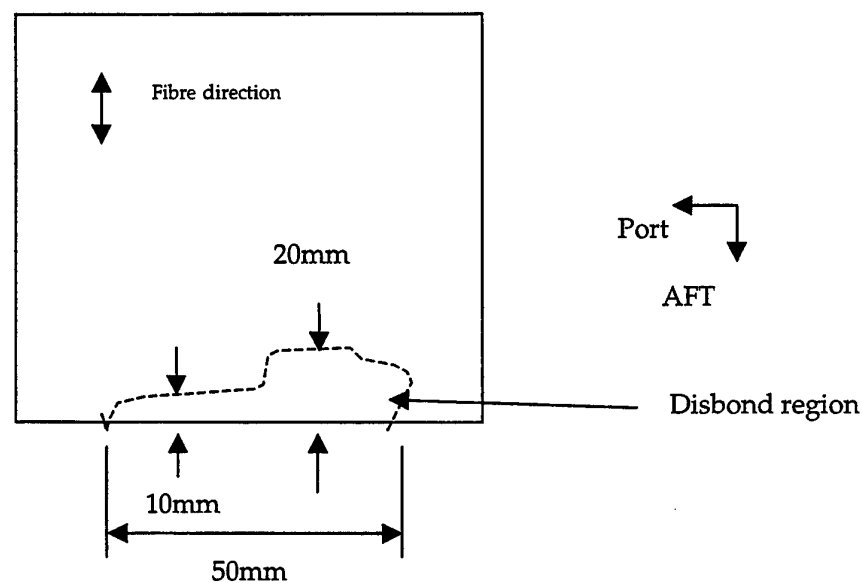


Figure 3. Disbond map for repair 'b'.



Photo 1. Showing disbond on rear edge of repair

### 2.2.3 Location 'c' – Trailing Edge Mid-Flap Lower Surface

Integrity of the repair was excellent with no abnormalities or signs of damage. The paint over the area was riddled with small sand like grains, leaving a sandpaper like finish over the repair.

### 2.2.4 Location 'd' – Number 2 Engine Pylon

Integrity of the repair was excellent, with no signs of damage, paint degradation or any other defects. The tap test confirmed the excellent condition of the repair.

### 2.2.5 Location 'e' – Fixed Leading Edge Nose- Port Wing

This repair showed significant erosion damage to the leading edge and top surface. There was evidence that the repair had been repainted many times during the life of the repair.

The main erosion damage was present at the leading edge of the repair. Within the first 12mm from the leading edge, most of the repair was eroded away, leaving traces of primer and adhesive only. The remaining ply damage extended up to 50mm back along the repair. The carrier scrim in the adhesive and the aluminium substructure was exposed in some areas, with some fibre tearout along the entire length of the repair. Damage on the leading edge of the repair effected all 4 plies.

Erosion had removed the adhesive and the primer from the areas where the aluminium surface was exposed due to lost fibers.

The second type of damage was at 45 degrees to the direction of the fibers, where foreign object damage (FOD) had caused paint stripping and damage to the surface of the repair as shown in photographs 2 and 3. On the rear edge of the repair part of the adhesive flash was also missing.

Despite the extensive damage and erosion, the bond integrity remained excellent with no abnormalities detected during the tap test.

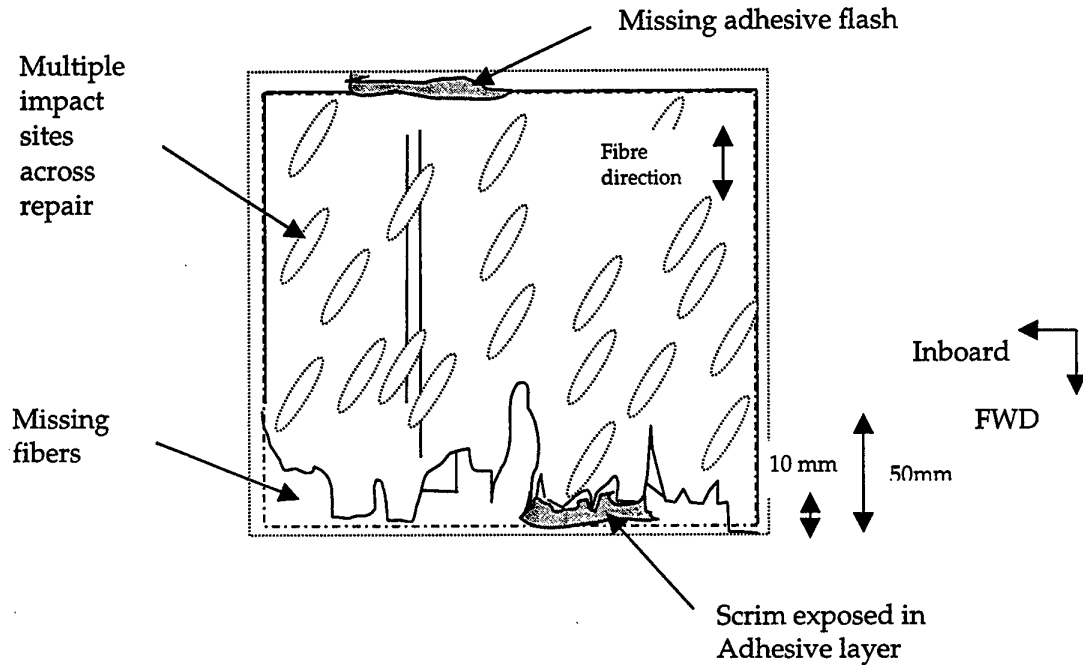


Figure 4. Damage due to erosion and impact on location 'e'. Bond integrity was excellent across remaining areas of repair.

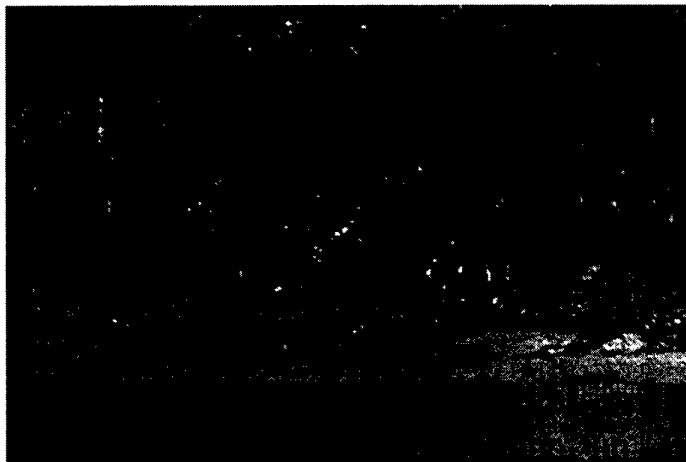


Photo 2. Showing damage to repair due to erosion at leading edge.

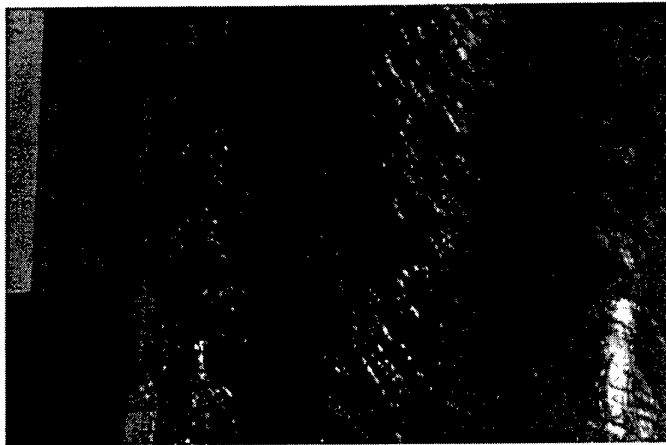


Photo 3. Showing damage to repair due to fod impact

#### 2.2.6 Location 'f' – Lower Skin of Port Stabiliser

The repair at this location showed significant signs of erosion, mainly to the leading edge. There was significant fiber-tear out along the length of the repair in the top ply (Figure 5, photo 4). Many loose fibres were present, which were removed for safety reasons during the inspection. There were signs of a small delamination in the corner of the repair between the outer layer and the second layer. Bond integrity was excellent with no other abnormalities detected during the tap test.

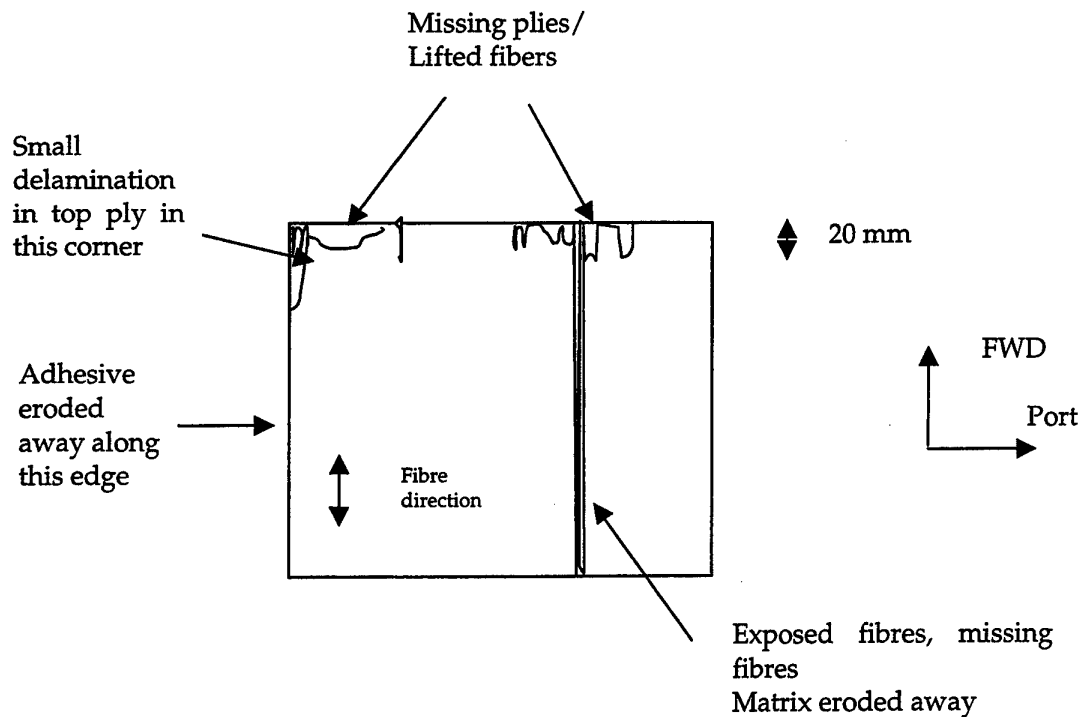
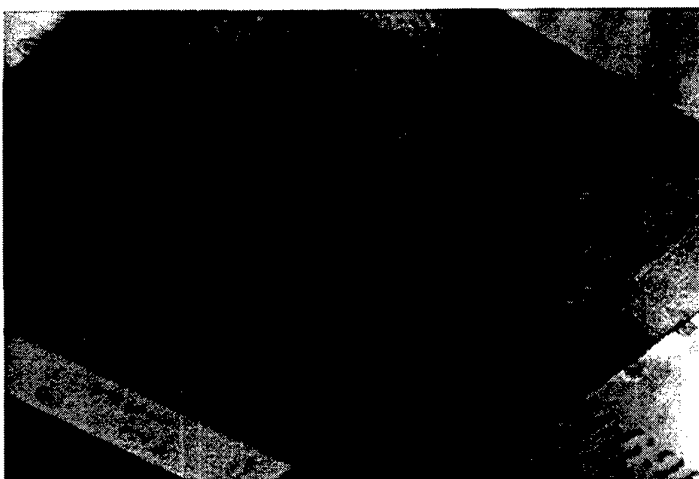


Figure 5. Damage map of location 'f'

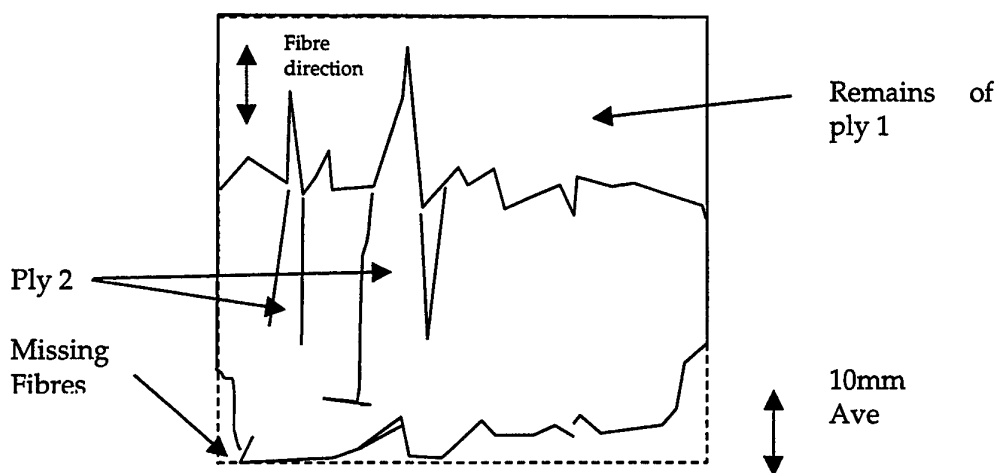


*Photo 4. Lower Stabiliser repair showing missing fibres along the length of the repair*

### 2.2.7 Location 'g' – Top Skin of Port Stabiliser

Significant erosion of this repair had occurred. Despite being painted over many times (Photo 6), indications were that up to 60% of the top ply, 10% of the second ply and approximately 5% of the third ply had eroded away. In the region 0 to 10mm from the leading edge, most of the fibres had eroded away over the width of the repair. In the areas where the repair had eroded away, the primer and grit blast surface had also been removed leaving a bare aluminium surface.

In one region, approximately 3mm x 3mm, the adhesive had eroded away from between the aluminium and the boron (Figure 6), leaving the fibres free. The remainder of the repair had excellent bond integrity.



*Figure 6. Damage map of region 'g' showing extent of ply stripping and damage due to erosion.*



*Photo 5. Top skin repair on stabiliser*

### 3. Discussion

#### 3.1 General

The inspection of the demonstrator repairs showed that despite exposure to severe environmental conditions, the bond integrity of the repairs was maintained. Erosion damage due to FOD was seen mainly on the leading edges of the repairs and to a lesser extent on the sides. This would be expected as the airflow and any object carried by the airflow would impact the leading edge and front of the repair first. Airflow alone does not seem to erode the repair. This is demonstrated by the integrity of the repairs on the Lap Joint (a) and No. 2 Pylon (d), which have been sheltered from FOD, yet were also exposed to high velocity airflow.

All eroded repairs had exposed surfaces that would have allowed moisture ingress into the adhesive bond line during the nine-year service. Despite this prolonged exposure to moisture there were no signs of bond degradation.

The most eroded repair was the top surface of the horizontal stabiliser (location 'g'), followed by the wing leading edge, (location 'e'), and then the lower surface of the horizontal stabiliser (location 'f').

The repair 'g', on the top surface of the stabiliser, was in line with the exhaust gas path of the number 2 engine. During takeoff and landing, with the aircraft in a nose high position, the exhaust gases ricochet off the runway and will carry any loose material up at high velocity towards the horizontal stabiliser.

The top surface of the stabiliser is more exposed than the lower surface while the aircraft is in this flight condition. This is due to the negative trim setting angle of the stabiliser which leaves the leading edge of the stabiliser rotated downwards with respect to the trailing edge, exposing more of the top surface than the lower surface to direct airflow.

The source of the impact damage to the repair at location 'e', the leading edge of the wing, was most probably due to material being thrown up from the nose wheels



during landing and takeoff manoeuvres. This was characterised by the angle of the FOD markings on the repair that traced a direct line between repair and nose wheel bogey.

The repair at location 'f', on the lower surface of the stabiliser was more sheltered from debris and FOD than the repair on the top surface 'g', already described above, and hence saw less damage.

At this time it was difficult to ascribe a reason for the disbond at location 'b' as there were no signs of erosion to the repair. It is possible that this disbond may have been caused by acoustic vibration causing fatigue in the adhesive. The indication could be of a disbond due to adhesion failure, however this would be unlikely as the condition of repair 'a' which had the same adhesive/cure system as 'b' exhibited very good durability with no indications of disbond due to adhesion failure.

The acoustic fatigue could have been caused by unsteady airflow over the top surface of the wing and flap while the flap segments were deployed. Confirmation of the disbond size and cause can only be determined by the careful removal of a segment of the repair for fractographic analysis.

The crack in the paint at location 'a' was possibly due to movement at the junction of the lap-joint seams and the repair. A full inspection of this repair was not possible due the thickness of the paint in the region. The condition of this repair will be determined at a later stage after removal of the paint.

There were no signs of cracking in any of the aluminium skin surrounding any of the repairs, implying that their presence did not lead to other structural problems such as fatigue cracking of the skin.

The excellent durability of the Versilok 201 adhesive and its use for room temperature cure applications for bonding boron repairs to aluminium structure has proven to be successful. In this program it has proven to be as durable as the film adhesive FM73 cured at 80°C for 8 hours or 120°C for 1 hour.

QANTAS procedures [2] describe the requirement to visually inspect the demonstrator repairs on VH-EBW during routine 'C' checks. The author found that although this procedure was being followed, there was no requirement for feedback on the status of the repairs to be forwarded to AMRL. Ideally, this would have been the case. Such a requirement could have identified the problems at location 'b' earlier, allowing close scientific monitoring and analysis of the degradation of the repair.

The mandatory reporting of the repair status would also have served as a useful training aid for QANTAS staff, so that in consultation with AMRL, they would have been able to learn about the levels of severity of environmental damage to the repairs and when to act. Eventually their experience would have led to in house expertise and knowledge of how to make informed decisions as to the severity of environmental degradation of bonded repairs and ways to manage it. Hindsight and experience now

shows that this requirement for mandatory reporting should have been raised by AMRL during the initial planning stages of the demonstrator program.

### 3.2 Civilian vs Military Durability Issues

Although civilian aircraft fly different flight profiles to military aircraft, especially fighters, the range of flight conditions and environments are similar for both. The comparison is more favourable for military transport aircraft (Boeing 707's, Lockheed C130s, VIP jets and other military transport types) as the manoeuvre types are less severe, low 'g' type events and subsonic flight. A fighter would typically see high 'g' turns and periods of sustained supersonic flight.

Thus it can be implied that although these demonstrator repairs were applied to a civilian aircraft, the lessons learnt from this program are directly applicable to military transport aircraft and at least the environmental durability aspects for fighter aircraft.

The recognition and basic understanding of the operating environment and flight profiles of civil and military aircraft is important when considering the application of bonded repairs to the aircraft, especially on an external skin. Location issues, such as surface temperature, interference with control surfaces, areas exposed to direct airflow and or susceptible to FOD must all be considered in repair design, as they may play a major part in the long term performance of the repair.

The inspection of the repairs applied to the QANTAS 747 after nine years of service has shown that the repairs, placed in the most environmentally susceptible locations of the aircraft still have excellent bond integrity.

The durability data gathered from this trial should be considered when addressing the issue of long-term durability of bonded repairs to any civilian or military aircraft in the future.

## 4. Conclusions

The inspection of the demonstrator bonded repairs showed that correctly applied bonded boron epoxy repairs are extremely durable. This was demonstrated by the severe environment that the repairs were exposed to over a period of 9 years and in excess of 37,000 hours of service and 7020 landings on a civilian aircraft. The demonstrator program has shown that repairs placed in areas of high susceptibility to FOD like leading edge surfaces need to have some form of protection to prevent erosion damage.

Should a repair need to be covered to prevent erosion damage, a possible fix could be a thin plastic polyurethane sheath that would encompass the entire leading edge and the sides of the repair- especially the adhesive around the edges. Minimal protection needs to be given to the main surface of the repair.

Repairs that are parallel to the airflow, like the sides of pylons, or slightly sheltered like the rear fuselage lap repair, have been demonstrated as needing little or no additional protection.

This demonstrator trial should be considered successful, with valuable information relating to the long-term effects of in service environmental damage to bonded composite repairs being obtained and reported on for future work in this area.

## 5. Recommendations

Based on the results of the demonstrator program for bonded repairs on a QANTAS B747-300 aircraft the following recommendations are made for any repairs which are placed on regions of an aircraft which could experience similar environmental conditions to those described in this report.

1. The location of any proposed bonded repair on an aircraft should be carefully assessed to ascertain its likelihood of exposure to FOD.
2. Those repairs placed on areas of the aircraft that have a high likelihood for FOD, should be protected with covering sheath of some sort. The minimum protection should encompass shielding the leading edge and sides of the repair with a sheath or protective sealant.
3. For future durability programs, the procedure for inspecting bonded repairs should incorporate the requirement for on-going collaboration and reporting of repair status between the organisation qualified in the application of the bonded repairs and the personnel inspecting the repairs. This would ensure that the correct transfer of technology, inspection procedures and results interpretation transpires between the two parties.
4. For the case of the repairs to VH-EBW, the inspection procedure should be amended to include a requirement for a report to be forwarded to AMRL after each 'C' check of the aircraft.
5. The demonstrator repairs at locations b, e and g should be removed before they degrade to a level where they may compromise the safety of the aircraft or the personnel working on the aircraft. These particular repairs have proven their durability through prolonged service and it is doubtful that much more information could be gleaned by leaving them on the aircraft.

The only reason the repairs at locations e and g should be left on the aircraft is for the trial fitment of an erosion protection shield for in service effectiveness trials.

6. The demonstrator repair at location 'f' should either be removed or a protective sheath installed over it to trial an erosion protection system.

7. The demonstrator repair at location 'a' should have the paint removed from over it to allow for a more thorough examination of the crack location and to confirm whether or not it was a crack in the repair or a defect in the paint.
8. The demonstrator repairs at locations a, c and d should remain in service and be inspected at regular intervals. Should they start to degrade they should also be removed from the aircraft.

## 6. Site Visit Details

The AMRL engineer on site to carry out the inspection was Rowan Geddes, while the QANTAS personnel were Mr Vince Romeo, Principal Structures Engineer, Mr Peter Hulskamp, Maintenance Supervisor/ Aircraft Recovery Coordinator and Mr John Lowe, Senior LAME. All staff were based at the Sydney Jet Base.

The inspection of the aircraft took place over a five-hour period on Sunday 5<sup>th</sup> September 1999 during a routine 'Super A Check' at Sydney Jet Base.

The author would like to acknowledge the assistance and cooperation of the QANTAS staff mentioned above, especially Mr Romeo, for their assistance during the inspection.

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- 1) Bartholomeusz R., Paul J., Roberts J., "Report on a visit to QANTAS in October 1990 relating to the bonded composite repair demonstrator program", 1991, Commonwealth of Australia (DSTO-ARL-TM-033).
- 2) QANTAS Engineering and Maintenance, Extra Work Sheet: EBW EW721937, 20 May 1998, Commercial in Confidence.

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Rowan C Geddes

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